Crop yield, weed cover and ecosystem multifunctionality are not affected by the duration of organic management

Herzog, Chantal ; Honegger, Adrian ; Hegglin, Django ; Wittwer, Raphaël ; de Ferron, Anne ; Verbruggen, Erik ; Jeanneret, Philippe ; Schloter, Michael ; Banerjee, Samiran ; van der Heijden, Marcel G A

DOI: https://doi.org/10.1016/j.agee.2019.106596

Originally published at:
Herzog, Chantal; Honegger, Adrian; Hegglin, Django; Wittwer, Raphaël; de Ferron, Anne; Verbruggen, Erik; Jeanneret, Philippe; Schloter, Michael; Banerjee, Samiran; van der Heijden, Marcel G A (2019). Crop yield, weed cover and ecosystem multifunctionality are not affected by the duration of organic management. Agriculture, Ecosystems Environment, 284:106596.
DOI: https://doi.org/10.1016/j.agee.2019.106596

Crop yield, weed cover and ecosystem multifunctionality are not affected by the duration of organic management

Chantal Herzog[a,b], Adrian Honegger[a], Django Hegglin[a], Raphaël Wittwer [a], Anne de Ferron[a], Erik Verbruggen[c], Philippe Jeanneret[d], Michael Schloter [e], Samiran Banerjee[a], Marcel G.A. van der Heijden[a,b]

[a] Plant-Soil-Interactions, Agroscope, Reckenholzstrasse 191, 8046 Zürich, Switzerland

[b] Department of Plant and Microbial Biology, University of Zurich, Zollikerstrasse 107, 8008 Zurich, Switzerland

[c] Plants and Ecosystems Research Group, Department of Biology, University of Antwerp, Universiteitsplein 1C, 2610 Wilrijk, Belgium

[d] Agricultural landscape and Biodiversity, Agroscope, Reckenholzstrasse 191, 8046 Zürich, Switzerland

[e] Comparative Microbiome Analysis, Helmholtz Zentrum München, 85764 Neuherberg, Germany

Corresponding author: Marcel van der Heijden

Agroscope

Reckenholzstrasse 191, CH-8046 Zürich

+41 44 377 7278

marcel.vanderheijden@agroscope.admin.ch

Highlights

- Conversion to organic management rapidly shifts agro-ecosystem functioning.
- Crop yield, weed cover and biodiversity are unaffected by management duration.
- Management practices do not affect ecosystem multifunctionality.

Abstract

Organic farming is gaining importance in view of its beneficial effects on soil quality, environmental performance and biodiversity. However, it is still unclear how organic management performs over time and whether the duration of organic management influences crop yield and ecosystem functioning. Here we compared 34 fields in Swiss farms assigned to four groups: 1) conventionally managed farms; 2) farms in transition to organic farming (in the 1st–3rd year); 3) farms converted moderately long ago (9–13 years); and 4) farms subjected to long-term organic farming (15–32 years). We selected one field per farm and examined in two subsequent years whether management practices (conventional vs. organic farming) and the duration of organic management affected crop yield, weed cover, soil fertility and biodiversity as well as the overall system performance, assessed as ecosystem multifunctionality. Maize yield (-6.0%) and wheat yield (-22.2%) decreased in organic compared to conventional fields. However, the duration of organic management did not affect crop yield. There was also no effect of the duration of organic management on weed cover but it was much higher under organic management, with mean values of 33.0% in organic compared to 2.0% in conventional fields in maize, and 13.4% compared to 1.2% in wheat, respectively. Soil fertility and microbial activities were not significantly different between management practices; only root colonization of arbuscular mycorrhizal fungi increased (+19.7%) under organic management in wheat. Overall, this study demonstrates a rapid shift of agro-ecological functions after conversion to organic farming and that the duration of organic management has no impact on crop yield, weed cover, soil fertility, and microbial activity.

Keywords: Organic farming; arbuscular mycorrhizal fungi; management duration; multifunctionality

1. Introduction

In agroecosystems, research is required to develop management strategies that provide adequate yields while reducing negative environmental impacts in the long term (Godfray et al., 2010; Godfray and Garnett, 2014; Tilman et al., 2002). Management practices such as the intensive use of synthetic pesticides and fertilizers in conventional farming systems can have severe environmental consequences (Pimentel, 2005; Pimentel et al., 2005) reducing biodiversity, contributing to the production of greenhouse gases, and causing eutrophication of surface water and drinking water. Changes in land use through agricultural intensification can not only affect biodiversity-driven ecosystem processes on the local but also on the global scale (Foley et al. 2005).

Organic farming has been promoted as a management strategy that could minimize agriculture's footprint on the environment (Reganold and Wachter, 2016). Even though the meaning of sustainable agriculture has often been debated in the past, there is little doubt that sustainable agriculture and many organic farming principles are closely linked (Rigby and Cáceres, 2001). Organic farming is characterized by no synthetic pesticide and no synthetic fertilizer use, with beneficial effects on the environmental performance and social well-being (Reganold and Wachter, 2016). It has been reported that organic farming has positive effects on soil fertility and biodiversity (Bengtsson et al., 2005; Mäder et al., 2002; Tuck et al., 2014; Tuomisto et al., 2012), it reduces soil erosion (Reganold et al., 1987; Seitz et al., 2019) and environmental impacts (Prechsl et al., 2017) and organic food has lower amounts of pesticide residues (Baker et al., 2002; Smith-Spangler et al., 2012). In Europe, strict rules are imposed on the use of pesticides even if certain substances are allowed under organic regulation in other parts of the world, e.g. rotenone and paraquat. However, organic pesticides such as copper may also have harmful environmental effects and should therefore be carefully assessed (Bahlai et al., 2010; Edwards-Jones and Howells, 2001).

Despite its beneficial effects, organic agriculture is being critically discussed because of reduced yield (de Ponti et al., 2012; Ponisio et al., 2015) and reduced yield stability (Knapp and van der Heijden 2018). Moreover, it is still poorly understood whether the duration of organic management affects crop yield and ecosystem functions. It is possible that yield declines over time under organic management due to the accumulation of pathogens and weeds or gradual decline in soil fertility after conversion because of reduced fertilizer input (Büchi et al., 2019). Concerns resulting from these uncertainties may discourage farmers from conversion to organic production (Ferjani et al., 2010). On the other hand, ecosystem functions that have been shown to be higher under organic management, such as soil structure (Shepherd et al., 2010), carbon sequestration (Gattinger et al., 2012), and interactions with beneficial soil symbionts such as arbuscular mycorrhizal fungi (AMF; Oehl et al., 2003) might further improve, the longer a field is under organic management. Thus, it is important to investigate to what extent the duration of organic management affects plant yield, biodiversity and environmental performance.

There is a growing interest in the assessment of ecosystem multifunctionality, which is the ability of ecosystems to provide multiple functions or services simultaneously (Manning et al., 2018). One pillar of this approach is the biodiversity-ecosystem functioning research (Byrnes et al., 2014; Gamfeldt et al., 2008; Hector and Bagchi, 2007; Wagg et al., 2014), the other being the land management research (Bateman et al., 2013; Manning et al., 2015; Nelson et al., 2009). To our knowledge, the approach has been mainly used in ecological studies, such as to evaluate biodiversity effects in grasslands or drylands (Delgado-Baquerizo et al., 2017; Maestre et al., 2012; Soliveres et al., 2016). In our study, we aimed at applying the concept in investigating to what extent ecosystem multifunctionality differs between organic and conventional management and whether it changes over time as a result of continuous organic farming. Further, we wanted to avoid an oversimplified estimation of multifunctionality and present several multifunctionality scenarios using a modified approach of Allan et al. (2015) to outline realistic land-use interests (e.g. production, sustainable soils and cultural services). Our approach of multifunctionality assessment entailed indicator variables of five ecosystem function categories: productivity (crop yield and weed cover), soil fertility ($C_{org,}$ P, K and Mg) and microbial activity (AMF colonization, microbial biomass C, soil respiration), biodiversity conservation (diversity of weeds, spiders and root associated fungi) and potential biocontrol of pests (represented by spider abundance). We varied the weights of the categories to represent multifunctionality scenarios with different land-use perspectives.

To this goal, we established a network in Switzerland comprising a total of 34 fields in organic and conventional farms. We addressed the following research questions: 1) Do productivity, soil fertility, soil microbial activity, biodiversity conservation, potential biocontrol of pests (assessed as spider abundance) and overall ecosystem multifunctionality differ between conventional and organic fields? 2) And are these parameters affected by the duration of organic management?

We hypothesized that there is 1) A rapid change in plant yield and ecosystem functioning after the conversion to organic management; 2) Reduced yield and increased weed cover in organically managed fields; and 3) A continuous enhancement of biodiversity and soil quality with the duration of organic management.

2. Materials and methods

2.1. Study sites and study design

We investigated 34 fields included in a farm network in the Cantons of Aargau, Zurich and Thurgau in Switzerland (Fig. 1). This area is characterized by a damp and mild climate with Cambisol and Luvisol as the predominant soil types. The farms were divided into four management groups: 1) conventionally managed farms (CONV; 9 farms); 2) organic farms that had been converted recently from conventional management and therefore still are in transition (TRAN; 9 farms; 1–3 years); 3) organic farms that were converted moderately long ago (BIO(9); 7 farms; 9–13 years); and 4) organic farms that had been subjected to long-term organic farming (BIO(15); 9 farms; 15–32 years after conversion to organic farming). Conventional farms were managed according to the "Proof of Ecological Performance" guidelines of the Swiss Federal Office for Agriculture ('Verordnung über die Direktzahlungen an die Landwirtschaft', 2013), which are the minimum requirements in order to obtain direct payments from the government and fulfilled by more than 90% of the Swiss farms. Organic farms were managed according to the guidelines of Bio-Suisse, the Swiss organization for organic farming ('https://www.bio-suisse.ch/') and were not allowed to use synthetic fertilizers as well as pesticides with substances that are synthetically produced and do not occur in nature.

Thirty-four maize (*Zea mays*) fields (one per farm) for ensilage of the whole plant followed by 24 winter wheat (*Triticum aestivum*) fields on the same parcels were investigated in 2011 and 2012, respectively (10 parcels were grown with other crops than wheat in 2012 and were therefore excluded from the 2012 analysis). The fields were part of a similar crop rotation across farm types with different kind of fodder production as pre-crops in 2010 (Supplementary Table A4). A total of 13 and 14 different varieties were used for maize and wheat respectively, and this varied irrespective of management strategy. Fields were ploughed prior to the sowing of maize and wheat.

All measurements except the spider sampling (see below) were taken within a sampling area, which was a 10 m defined radius around a GPS tagged point (Supplementary Fig. A.6). A buffer zone of at least 20 m was kept from the border of the field to avoid edge effects, and steep or uneven ground was avoided to gather representative data. A summary of the variables assessed in each sampling year (e.g. for maize and wheat) is presented in Table 1 and 2. Questionnaires were collected to assess management information, such as animal stock, crop rotation, fertilizer inputs and weed control operations. For the calculation of nutrient inputs applied with organic fertilizers, we used reference values from GRUDAF (Flisch et al., 2009), the Swiss fertilization guideline for arable and forage crop production.

2.2. Yield and weed assessment

For maize, samples for determining yield were taken shortly before harvest between September and mid-October 2011. In the sampling area, two meters from four rows of maize were cut and shredded. The dry matter content of maize was determined after drying a composite sample of about 2 kg at 100 °C for 24 hours. For one of the BIO(15) maize field, no yield data was available due to heavy hail damage. For wheat, yield samples were collected in July 2012 from four randomly chosen sub-plots (0.6 x 0.4 m) within the sampling area. A subsample of grains was oven-dried at 100 °C for 24 hours to calculate the dry matter (DM) grain yield in decitonne (dt) per hectare. Weed species and the relative ground cover in percentage of each species were determined visually at three randomly selected areas within the sampling area; 0.75 x 0.75 m for maize in July 2011 and 1 x 1 m for wheat in June 2012. One wheat field (TRAN) had to be excluded from the weed assessment as there was only lodged wheat in the sampling area. For the analysis, we averaged data of the three sub-plots.

2.3. Soil chemical properties

In early March 2012, a composite soil sample was collected in each sampling area at 20 cm depth and stored at 4° C until further processing. Soils were analyzed according to the reference methods of the Swiss Federal Institutes of Agricultural Research (Eidgenössische Forschungsanstalten FAL, RAC, 1996). For texture, clay and silt contents were assessed in water suspension aliquots by sedimentation analysis. Soil pH was measured from an aqueous soil suspension and a water to soil ratio of 1:2.5 based on the potentiometric measurement of hydrogen ion activity. The organically bound carbon (C_{org}) was oxidized in excess by the addition of potassium dichromate ($K_2Cr_2O_7$). The remaining $K_2Cr_2O_7$ solution was titrated back with a Fe(II) solution. Given the redox reaction, C_{org} (mass-percentage) can be determined, which is proportional to the consumed $K_2Cr_2O_7$.

Nutrient contents were determined from soil samples collected in July 2012 to allow two months of time after the last fertilizer application. Soils were 2 mm sieved prior to analysis. To extract easily soluble phosphorus (P) and potassium (K) we used a ratio of soil to CO_2-saturated water of 1:2.5. The extracted P was converted to phosphor molybdenum blue with ammonium molybdate in acidic solution. The resulting blue coloration was determined photometrically at a wavelength of 750 nm. P was determined by flame emission at a wavelength of 769.9 nm. The easily exchangeable magnesium (Mg) was extracted from the soil with a $CaCl_2$ solution. This method is based on the ion exchange of Mg with calcium (Ca). The ratio of soil to 0.0125 M $CaCl_2$ solution was 1:10. Mg was determined by atomic absorption spectroscopy at a wavelength of 202.6 nm.

2.4. Soil biological properties

To assess basal respiration, soils were pre-incubated for seven days at 50% water holding capacity to stabilize microbial communities after sample preparation. Before the actual measurement, soils were incubated in a closed system with a NaOH solution for 24 hours and transferred to a new bottle to absorb the emitted CO_2 in a NaOH solution over 72 hours. The resulting Na_2CO_3 was precipitated with $BaCl_2$ and the unused NaOH was determined by titration with HCl (Isermeyer, 1952; Jäggi, 1976). Soil microbial biomass carbon (MBC) was measured by chloroform-fumigation-extraction according to Vance et al., (1987). Fresh soil samples corresponding to 20 g dry soil, were fumigated with chloroform for 24 hours. Organic C content was measured by infrared spectrometry after combustion at 850 °C (DIMATOC® 2000, Dimatec, Essen, Germany).

2.5. AMF colonization and the overall root associated fungal communities

In August 2011, a pooled sample of fine roots from five maize plants, cut in pieces of about 2 cm length, was stored in 50% EtOH for the analysis of root colonization by AMF. Likewise in June 2012, roots were collected from six wheat plants and an additional subsample was preserved in liquid nitrogen and stored at – 80 °C for subsequent molecular analyses of fungal communities. The percentage of root colonization by AMF was assessed following the procedure of Vierheilig *et al.* (1998). In brief, roots were cleared in 10% KOH in a water bath at 80 C° for 25 min and stained with a 5% ink-vinegar solution for 15 min. Roots were prepared on a microscopy slide and colonization was measured with a light microscope at a magnification of x 200 using a modified line-intersection method for a hundred intersections per sample. (McGonigle et al., 1990).

A detailed description of sample preparation and bioinformatic analysis of root associated fungal communities in wheat can be found in the study of Verbruggen et al. (2014). In brief, DNA was extracted from 7 to 10 mg lyophilized roots using the Dneasy Plant Mini Kit. PCR was conducted using the Firepol DNA polymerase (Solis Biodyne, Tartu, Estonia) and the general fungal primers ITS1F (Gardes and Bruns, 1993) and ITS4 (White et al., 1990). Amplicons were sequenced on four 1/8 plateregions using the Roche 454 FLX Titanium pyrosequencing (Roche, Branford, CT, USA). We obtained 519,110 reads with an average read length of 413.79 bp. Reads were filtered, reads shorter than 200 bp were excluded followed by clustering and classification of operational taxonomic units (OTUs). All samples were resampled to the minimum read number to account for differences in sequencing depth, leaving a total of 394 fungal OTUs.

2.6. *Spiders*

Spider data were collected between July and August 2011 in 31 out of 34 maize fields using a suction sampling method (Jeanneret et al., 2012) with a modified vacuum shredder powered by a two-stroke engine (Stihl 86-D). Five sub-samples per field were randomly collected (Supplementary Fig.A6), pooled and stored in 70% EtOH. Details on the sampling procedure are given in Supplementary data A.1. Spiders were attributed the family and if possible the genus using Roberts (1995) and then identified as morphospecies which are reliable surrogates for taxonomic unit species for studying patterns of species richness and diversity (Oliver and Beattie, 1996). In our analysis, we averaged the three sampling rounds to get one mean value for spider abundance per species.

2.7. Multifunctionality assessment

The indicator variables used to assess multifunctionality (16 in total, see Table 3) were classified into five ecosystem function (EF) categories, namely: 1)"productivity", 2) "soil fertility", 3) "soil microbial activity", 4) "biodiversity conservation", and 5) "potential biological control of pests". A detailed description of the classification and calculation of *z*-scores can be found in Supplementary data A.2. We calculated standardized *z*-scores for the 16 indicator variables (Wagg et al., 2014) and averaged them according to Table 3 to build the five EF categories. For the purpose of expressing different management priorities (e.g. yield or soil protection oriented), Allen et al. (2015) used specific sets of functions and services with different weightings in order to represent different land-use perspectives: 1) “production only”; 2) “sustainable soils”; 3) “sustainable soils and crops”; 4) “equal weight multifunctionality”; and 5) “cultural multifunctionality”. Similar to Allan et al. (2015) but adapted to our context, we calculated four multifunctionality indices by averaging z-scores of the five EF categories after giving them different weightings: (M1) “production” with 50% of the weight for “productivity” and 50% weight for the remaining variables; (M2) “sustainable soils” with 25% of the weight for each “productivity “, “soil microbial activity” and “soil fertility” and 25% weight for the remaining variables; (M3) “equal weight multifunctionality” weighs all EF categories equally; and (M4) “biodiversity” with 50% of the weight on the EF category “biodiversity” (Fig. 2). The scenarios indicate a gradient from prioritizing agricultural production (M1) to biodiversity (M4) via a neutral scenario (M3).

2.8. Statistical analyses

In total, 14 and 20 response variables were individually analyzed for maize and wheat fields, respectively (Tables 1, 2). All statistical analyses were performed using R version 3.5.0 (R Core Team, 2018). As the assumptions for parametric statistics were violated for nearly all variables, we tested the effects of the management groups i.e. CONV, TRAN, BIO(9) and BIO(15), on the examined variables for significant differences ($\alpha = 0.05$) using the non-parametric Kruskal-Wallis test. Multiple comparisons of group means were performed using the *kruskalmc* function from the *pgirmess* package. Weed cover was averaged over the three quadrats and the Shannon-Wiener index of diversity was calculated using the *diversity* function available in the *vegan* package. For the analysis of fungal communities, read numbers of operational taxonomic units (OTUs) were rarefied for each sample to the minimum read number obtained in all samples using the *phyloseq* package. Alpha diversity of the rarefied data was calculated for each field using the *estimate_richness* functions. We performed a principal component analysis (PCA) using the *prcomp* function to visualize the variables included in the multifunctionality analyses (Table 3) and the management groups in the multidimensional space. To test whether variances in our data can be explained by the management groups, we run a permutational multivariate ANOVA (PERMANOVA) with the Euclidean distance matrices using the *adonis* function with 999 permutations. Pairwise correlations were tested for both study years using the *cor* function based on spearman rank correlation coefficient and visualized in a correlogram using the *corrplot* function. Management group effects on multifunctionality indices were analyzed the same way as the individual variables and visualized with boxplots. Simple linear regressions were further used to establish the relation of yield and multifunctionality with organic management duration. Relationships were visualized by scatterplots including the regression lines. If not stated otherwise, graphs were created using the *ggplot2* package.

3. Results

3.1. Crop yield and weed cover

Yields of organic fields were on average 6.0% lower than in conventional fields for maize (Chi square = 1.191, df = 1, p = 0.276) and 22.2% for wheat respectively (Chi square = 6.947, df = 1, p = 0.008). Wheat and maize yield was not affected by the duration of organic management (Fig. 3). Fields in transition to organic agriculture (1-3 years) had similar yields as fields managed organically between 9 and 32 years for maize (Chi square = 0.556, df = 1, p = 0.456) and wheat (Chi square = 0.042, df = 1, p =

0.838). Moreover, weed cover showed similar patterns for both crops with clearly higher weed cover in organic fields, including those under conversion, and similar to yield, weed cover was not affected by the duration of organic farming (Figure 3).

3.2. Effect of organic farming on biodiversity, soil microbial activity and soil fertility

Weed species richness varied depending on the treatment and was positively affected by organic management in both crops (Tables 1, 2). Weed diversity, reflected by the Shannon index, was on average significantly increased in organic fields in maize (+215.3%; Chi square = 14.53, df = 1, p = < 0.001) and wheat (+92.9%; Chi square = 5.083, df = 1, p = 0.024). Species richness, evenness and diversity of both spiders and root associated fungi were neither affected by the management nor by the duration of organic farming (Tables 1, 2). Spider abundance was positively correlated with weed species richness (Supplementary Fig. A.7).

AMF colonization in maize was similar in conventional compared to organically managed plots (+1.6% in organic; Chi square = 0.152, df = 1, p = 0.696). AMF colonization in wheat was significantly higher in BIO(9) than in conventional fields, indicating an overall positive effect of organic farming practices on AMF (+19.7%; Chi square = 5.083, df = 1, p = 0.024; Table 2). Both MBC and soil respiration did not differ significantly between management groups, and neither did C_{org}, although it tended to be higher in organically managed fields (+15.4% in organic; Chi square = 2.624 df = 1, p =0.105). P and Mg in the soil did not respond to management while K was clearly higher in BIO(15) soil compared to TRAN, BIO(9) but not conventionally managed fields (Table 2).

3.3. Effect of organic farming on ecosystem multifunctionality

A PCA revealed a clustering of conventional farms (Fig. 4). PERMANOVA further showed a statistically significant difference between conventional and organic fields, including fields in transition for maize ($F_{1,20}$= 2.281, p = 0.005) and wheat ($F_{1,20}$= 2.223, p = 0.006). The indicator variables best explaining differences among the treatments in the maize data were spider abundance, weed species richness and spider evenness (principal component PC1) as well as yield, weed cover and spider richness (principal component PC2). For wheat, it was MBC, soil respiration and C_{org} for PC1 and yield, weed species richness and weed cover for PC2.

Our analysis did not reveal significant differences between management groups on the four multifunctionality indices, namely "(M1) production", "(M2) sustainable soils", "(M3) equal weight multifunctionality" and "(M4) biodiversity" (Fig. 5; Supplementary A.8), despite that the EF category "productivity" was higher in conventional fields. Although differences were not significant, mean multifunctionality of the organic farms in M1 was the highest in the long-term group BIO(15) and on a similar level as the conventional farm group. Moreover, for M2-M4, multifunctionality tended to increase with organic management duration and the long-term organic farms showed the highest mean values. Our results demonstrated a response of crop yield, weed cover and environmental performance to the conversion from organic to conventional farming but no change along with organic farming duration.

4. Discussion

4.1. Yield and weed cover are determined by management practice but not management duration

In agricultural research, yield is one of the key factors to consider when evaluating different food production systems. In our study, we were able to explore two important questions related to crop yield under organic farming: 1) Do yield and weed cover differ between conventional and organic fields? and 2) Are the two parameters affected by the duration of organic management? On average, we found 6.0% lower yield for maize and 22.2% for wheat, respectively (Tables 1, 2) which is in line with earlier reports from Switzerland that showed 10% and 20% lower yield for maize and wheat, respectively (Jossi et al., 2009; Zihlmann et al., 2010). While a range of studies investigated organic yield gaps, very few tested whether the duration of organic management altered plant yield and they largely focused on the transitional period (e.g. Gopinath et al., 2008; Martini et al., 2004). Our study shows no significant decline of maize- and wheat yields with increasing duration of organic management. Thus, our results indicate, that under Swiss farming conditions, farmers interested in a conversion to organic farming should not be concerned with a significant gradual decline of yield. However, in certain cases, the yield gap can be more pronounced, for example Larsen et al. (2014) observed a reduction of more than 50% maize yield in organic compared to conventional treatments. Moreover, the findings of Schrama et al. (2018) show that closing the yield gap between organic and conventional farming can be a question of time and that organic farms potentially result in higher spatial stability due to slow changes in soil properties.

Besides yield losses, weed cover is a major problem under organic management. Unlike conventional systems that allow the use of herbicides as an effective weed control strategy, organic farmers have to pursue alternative weed control strategies such as manual removal, thermal methods or tillage. Although soil cover by weeds generally increased after conversion to organic farming, the weed abundance did not significantly increase with time after conversion from conventional to organic management. In the long-term organic farm group BIO(15), values of weed cover were between 5.3% and 78% for maize and between 4.2% and 25.1% for wheat, respectively. This large range can partly be explained by the fact that weed cover per se is strongly influenced by site conditions and other context dependent features such as weed control strategies and weed tolerance of farmers.

Weed cover was negatively correlated with wheat but not maize yield, which could explain why the yield gap was much stronger for wheat (-22,2%) than maize (-6%). This observation could indicate a stronger crop-weed competition for wheat compared to maize, and we encourage future research to test this assumption and investigate how crops differ in their competing ability with weeds. Another explanation that needs to be tested, is that a large amount of farm manure (mostly slurry and also in conventional farms) is generally applied to maize and that mineralization time fits better with crop vegetation, thus reducing fertilization gap between organically and conventionally managed fields.

4.2. Organic farming maintains soil fertility

Preservation of fertile soils is essential for sustainable food production system but it is still debatable whether soil nutrient contents can be kept at an optimum level over a long period of time under organic farming. Previous research showed reduced levels of P and K in soils under organic management, which was mainly explained by reduced fertilizer inputs as well as foregoing the use of mineral fertilizers (Gosling and Shepherd, 2005). In our comparison of plant available soil nutrients of organic and conventional farms there was no difference in P and Mg contents between both farming systems. Surprisingly for K, the long-term organic farm group BIO(15) showed the highest levels in our study. This can be explained by the large amount of nutrient-rich organic fertilizers, mainly in the form of potassium oxide (K_2O) rich cattle manure applied on organic farms. Thus, nutrient supply should not discourage farmers from a conversion to organic management, especially for mixed farms. This study did not assess the level of mineral N (N_{min}) in the soil, which should be considered in future work. However, we evaluated fertilizer inputs and the results show significantly lower N-fertilization in BIO(15) than CONV fields for maize, and in BIO(9) and BIO(15) compared to CONV fields for wheat (Tables 1, 2; Supplementary data A.3). Moreover, C_{org}, an important indicator for soil quality (Liu et al., 2006; Reeves, 1997), was also unaffected by management (e.g. slight higher values (+15.4%) under organic management). Higher C_{org} values in organic compared to conventional farming systems have been reported in literature (Reganold, 1995, 1988), an earlier Swiss study also found no significant differences in C_{org} between organic and conventional fields (Oberholzer et al., 2009). It is important to note that most Swiss farms are mixed farms, with dairy and arable cropping production, that can use their cattle manure on arable lands (Fliessbach et al., 2007). As a result, not only organically but also conventionally managed fields are supplied with organic fertilizer, which may be a key factor resulting in less pronounced disparities in C_{org} in Swiss agroecosystems.

4.3. Soil microbiology only differs in AMF root colonization

Soil microbial biomass is sensitive to agricultural management practices (Wardle, 1992) and can be used as an indicator for soil health and environmental sustainability (Singh and Gupta, 2018). We did not find a significant difference in MBC between the management groups in our study, although organically managed fields tended to have higher MBC (+23.2%). More diverse crop rotations and the widespread application of farmyard manure of conventional farms in comparison to other countries may partly explain the difference between our results and that found in field experiments or other countries (Araújo et al., 2008; Gunapala and Scow, 1998; Mäder et al., 2002; Tu et al., 2006). Through a wider range of field sites, our results support findings of Swiss study in which there was no difference in microbial biomass between the two farming systems in a field experiment (Fliessbach et al., 2007).

Arbuscular mycorrhizal fungi (AMF) are important bioindicators in agricultural systems because they influence plant growth and are sensitive to changes in land use type and intensity (Oehl et al., 2011; Verbruggen et al., 2010). While there was no management effect on maize, we found a positive impact of organic farming on AMF root colonization in wheat (Tables 1, 2). In contrast to a comparable study performed in the Netherlands (Verbruggen et al., 2010), we could not find a response of AMF colonization to the duration of organic farming. However, overall differences between organic and conventional management are stronger in the Netherlands than in Switzerland, e.g. many maize fields of the Dutch study were under long-term mono-cropping. Moreover, the strict Swiss management regulations, e.g. crop rotation and reduced fertilizer use, also in conventionally managed fields, may explain why soil respiration, MBC and AMF root colonization did not greatly differ between conventional and organic farming.

4.4. No increase of biodiversity along with management duration

In our study, we only found positive effects of organic farming on weed species richness and diversity but not on overall spider- or root associated fungal communities and they were not affect by management duration. Spiders, which are important for biological pest control in agricultural fields (Marc and Canard, 1997; Samu and Szinetár, 2002; Sunderland and Samu, 2000) did not differ in their abundance or diversity between farming practices. Though Hole et al. (2005) concluded that most of the reviewed studies reported higher spider abundances under organic management, differences were not always statistically significant across sites and years. In accordance with earlier studies showing that the number and variety of spiders mainly depend on the habitat structure (Hole et al., 2005; Jeanneret et al., 2003; Samu and Szinetár, 2002), we found that spider abundances were positively correlated with weed species richness.

Even though we expected more diverse spider communities in organically managed fields, e.g. through higher crop diversification, spiders also depend to a large extent on the surrounding landscape (Sunderland and Samu, 2000).

Root associated fungal communities did not differ between management groups. Our finding is in accordance with Hole et al. (2005) who observed a little difference in fungal communities between organic and conventional systems. Banerjee et al. (2019) also found no differences in fungal diversity between organic and conventional fields. However, in that study organically managed fields harbored a much more complex fungal network with more keystone taxa. Furthermore, Verbruggen et al. (2014) discovered that *Sebacinales* were only present in organic fields of our farmer network. This finding is particularly interesting because these endophytic fungi are known to form beneficial interactions with their host plants, involving enhanced resistance to abiotic and pathogen stress (Michael et al., 2016). Future research should therefore test the potential of *Sebacinales* to serve as bio-indicators for sustainable land use (Verbruggen et al., 2014) and complement other already well-known indicator groups such as AMF (Jansa et al., 2014; Oehl et al., 2011). Comprehensive meta-analyses from Bengtsson et al. (2005) and Tuck et al. (2014) reported an overall positive effect of organic farming on species richness and abundance but stated that the effects mostly depended on organism identities and landscape types, and that differences are most pronounced in intensively managed systems. Across a large range of European farming systems and environmental conditions, Schneider et al. (2014) also showed an overall higher species richness (plants, earthworms, spiders, bees) in organic systems than in conventional ones at plot scale but not farm scale. Our study contributes to the conclusion that effects of organic farming on biodiversity depend on the organisms under study as well as on the scale investigated.

4.5. Agro-ecological functioning and multifunctionality across management groups

Principal component analysis (Fig. 4) showed that organically managed fields including the fields recently converted to organic management clustered together while conventional fields formed a separate cluster. This outcome suggests a rapid shift of agro-ecological functions after a conversion to organic farming as fields of farms in transition are more similar to long term organic than to conventional managed fields. The clustering of conventional fields versus organic fields was mainly determined by yield, weed abundance and weed species richness. Yield and weeds can respond quickly to a change of management (e.g. because under organic management weeds are no longer suppressed with herbicides and yield is reduced because the amount of directly available nutrients is lower while mineral fertilizers cannot be applied directly when crop requirements for fertilizers are highest). Future studies investigating agro-ecological functioning of conventional and organically managed fields should also focus on variables that may respond more slowly to a transition to organic farming (e.g. soil quality indicators not assessed in this study) and include more fields, if possible fields that have been under organic management for over 50 years.

In our multifunctionality assessment, we did not find clear management effects on the four ecosystem multifunctionality scenarios. This could be explained by several factors. First, there was substantial variations between individual fields within treatments. Second, differences between treatments were apparently not strong enough and opposing effects of different variables (e.g. higher yield, but lower weed diversity in conventionally managed fields, and opposite effects in organically managed fields) cancelled out effects. Moreover, although we analyzed a wide range of indicator variables (16 in total), it is unfeasible to assess all possible functions (Manning et al., 2018) and we might have missed important variables. The scenario that focuses on production showed no further decrease of crop yield along with organic management duration. The remaining scenarios, namely sustainable soils, equal weight and biodiversity, all showed increasing multifunctionality with ongoing organic management, which implied a positive trend of the impact of ongoing organic farming on the overall environmental performance when emphasizing on alternative land use objectives rather than productivity alone. This increase could be driven by the higher soil-K contents resulting from the use of organic fertilizer that is rich in K and widely applied on organic farms, as well as the higher weed species richness and overall AMF colonization we observed in organically managed fields. To better understand how organic management influences ecosystem multifunctionality in the long-term, we need further studies that assess a large number of fields over multiple years and test a comprehensive set of variables that represent a wide range of ecosystem functions and services.

5. Conclusion

A range of studies compared yield, biodiversity and environmental performance of organic versus conventionally managed fields. However, it is still unclear whether the duration of organic management affects plant yield and ecosystem functions. Our investigation demonstrated that crop yield, weed cover, soil fertility, biodiversity and potential biocontrol of pest through spiders are not affected by the duration of organic management. Moreover, we found positive effects of organic farming on AMF root colonization, weed species richness and soil-K contents. The present study may help reduce concerns of farmers related to long-term organic farming. Finally, our results may contribute to a better understanding of the role of different farming systems on the environmental performance.

Acknowledgements

We are very grateful to the participating farmers for making our study possible. We would like to thank C. Wagg and F. Walder for support with the statistical and multifunctionality analyses. We further thank the plant-soil interaction research group and function laboratory of Agroscope Reckenholz for helpful inputs and for soil analyses respectively and A. Lechmann for creating the study map. We thank the Rillig Laboratory at the Freie Universität Berlin for support in analysis of root fungal diversity. Funding was provided by the Swiss National Science Foundation (grant 31003A-166079). We also thank two anonymous reviewers for their constructive comments.

References

Allan, E., Manning, P., Alt, F., Binkenstein, J., Blaser, S., Blüthgen, N., Böhm, S., Grassein, F., Hölzel, N., Klaus, V.H., Kleinebecker, T., Morris, E.K., Oelmann, Y., Prati, D., Renner, S.C., Rillig, M.C., Schaefer, M., Schloter, M., Schmitt, B., Schöning, I., Schrumpf, M., Solly, E., Sorkau, E., Steckel, J., Steffen-Dewenter, I., Stempfhuber, B., Tschapka, M., Weiner, C.N., Weisser, W.W., Werner, M., Westphal, C., Wilcke, W., Fischer, M., 2015. Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. Ecol. Lett. 18, 834–843. https://doi.org/10.1111/ele.12469

Araújo, A.S.F., Santos, V.B., Monteiro, R.T.R., 2008. Responses of soil microbial biomass and activity for practices of organic and conventional farming systems in Piauí state, Brazil. Eur. J. Soil Biol. 44, 225–230. https://doi.org/10.1016/j.ejsobi.2007.06.001

Bahlai, C.A., Xue, Y., McCreary, C.M., Schaafsma, A.W., Hallett, R.H., 2010. Choosing organic pesticides over synthetic pesticides may not effectively mitigate environmental risk in soybeans. PLoS One 5. https://doi.org/10.1371/journal.pone.0011250

Baker, B.P., Benbrook, C.M., Groth III, E., Lutz Benbrook, K., 2002. Pesticide residues in conventional, integrated pest management (IPM)-grown and organic foods: insights from three US data sets. Food Addit. Contam. 19, 427–446. https://doi.org/10.1080/02652030110113799

Banerjee, S., Walder, F., Büchi, L., Meyer, M., Held, A.Y., Gattinger, A., Keller, T., Charles, R., van der Heijden, M.G.A., 2019. Agricultural intensification reduces microbial network complexity and the abundance of keystone taxa in roots. ISME J. https://doi.org/10.1038/s41396-019-0383-2

Bateman, I.J., Harwood, A.R., Mace, G.M., Watson, R.T., Abson, D.J., Andrews, B., Binner, A., Crowe, A., Day, B.H., Dugdale, S., Fezzi, C., Foden, J., Hadley, D., Haines-Young, R., Hulme, M., Kontoleon, A., Lovett, A.A., Munday, P., Pascual, U., Paterson, J., Perino, G., Sen, A., Siriwardena, G., van Soest, D., Termansen, M., 2013. Bringing ecosystem services into economic decision making: Land use in the United Kingdom. Science 341, 45–50. https://doi.org/10.1126/science.1234379

Bengtsson, J., Ahnström, J., Weibull, A., 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. J. Appl. Ecol. 42, 261–269. https://doi.org/10.1111/j.1365-2664.2005.01005.x

Büchi, L., Georges, F., Walder, F., Banerjee, S., Keller, T., Six, J., van der Heijden, M.G., Charles, R., 2019. Potential of indicators to unveil the hidden side of cropping system classification: actual differences and similarities in cropping practices between conventional, no-till and organic systems. Eur. J. Agron. 109. https://doi.org/https://doi.org/10.1016/j.eja.2019.125920

Byrnes, J.E.K., Gamfeldt, L., Isbell, F., Lefcheck, J.S., Griffin, J.N., Hector, A., Cardinale, B.J., Hooper, D.U., Dee, L.E., Emmett Duffy, J., 2014. Investigating the relationship between biodiversity and ecosystem multifunctionality: challenges and solutions. Methods Ecol. Evol. 5, 111–124. https://doi.org/10.1111/2041-210X.12143

de Ponti, T., Rijk, B., van Ittersum, M.K., 2012. The crop yield gap between organic and conventional agriculture. Agric. Syst. 108, 1–9. https://doi.org/10.1016/j.agsy.2011.12.004

Delgado-Baquerizo, M., Eldridge, D.J., Ochoa, V., Gozalo, B., Singh, B.K., Maestre, F.T., 2017. Soil microbial communities drive the resistance of ecosystem multifunctionality to global change in drylands across the globe. Ecol. Lett. 20, 1295–1305. https://doi.org/10.1111/ele.12826

Edwards-Jones, G., Howells, O., 2001. The origin and hazard of inputs to crop protection in organic farming systems : are they sustainable? Agric. Syst. 67, 31–47.

Eidgenössische Forschungsanstalten FAL, RAC, F., 1996. Schweizerische Referenzmethoden der Eidgenössischen landwirtschaftlichen Forschungsanstalten, Band 1, Version 2015.

Ferjani, A., Reissig, L., Mann, S., 2010. Biolandbau in der Schweiz – wer steigt aus , wer steigt ein ? Agrar. Schweiz 1, 142–147.

Fliessbach, A., Oberholzer, H.R., Gunst, L., Mäder, P., 2007. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. Agric. Ecosyst. Environ. 118, 273–284. https://doi.org/10.1016/j.agee.2006.05.022

Flisch, R., Sinaj, S., Charles, R.W.R., 2009. Grundlagen für die Düngung im Acker- und Futterbau (GRUDAF). Agrar. Schweiz 16, 1–80.

Foley, J.A., Defries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. Science 309, 570–574. https://doi.org/10.1126/science.1111772

Gamfeldt, L., Hillebrand, H., Jonsson, P.R., 2008. Multiple functions increase the importance of biodiversity for overall ecosystem functioning. Ecology 89, 1223–1231. https://doi.org/10.1890/07-1861.1

Gardes, M., Bruns, T.D., 1993. ITS primers with enhanced specificity for basidiomycetes - application to the identification of mycorrhizae and rusts. Mol. Ecol. 2, 113–118. https://doi.org/10.1111/j.1365-294X.1993.tb00005.x

Gattinger, A., Muller, A., Haeni, M., Skinner, C., Fliessbach, A., Buchmann, N., Mäder, P., Stolze, M., Smith, P., Scialabba, N.E.-H., Niggli, U., 2012. Enhanced top soil carbon stocks under organic farming. Proc. Natl. Acad. Sci. 109, 18226–18231. https://doi.org/10.1073/pnas.1209429109

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2010. Food security: the challenge of feeding 9 bllion people. Science 327, 812–818. https://doi.org/10.1126/science.1185383

Godfray, H.C.J., Garnett, T., 2014. Food security and sustainable intensification. Philos. Trans. R. Soc. B 369, 20120273–20120273. https://doi.org/10.1098/rstb.2012.0273

Gopinath, K.A., Saha, S., Mina, B.L., Pande, H., Kundu, S., Gupta, H.S., 2008. Influence of organic amendments on growth, yield and quality of wheat and on soil properties during transition to organic production. Nutr. Cycl. Agroecosystems 82, 51–60. https://doi.org/10.1007/s10705-008-9168-0

Gosling, P., Shepherd, M., 2005. Long-term changes in soil fertility in organic arable farming systems in England, with particular reference to phosphorus and potassium. Agric. Ecosyst. Environ. 105, 425–432. https://doi.org/10.1016/j.agee.2004.03.007

Gunapala, N., Scow, K.M., 1998. Dynamics of soil microbial biomass and activity in conventional and organic farming systems. Soil Biol. Biochem. 30, 805–816. https://doi.org/https://doi.org/10.1016/S0038-0717(97)00162-4

Hector, A., Bagchi, R., 2007. Biodiversity and ecosystem multifunctionality. Nature 448, 188–190. https://doi.org/10.1038/nature05947

Hole, D.G., Perkins, A.J., Wilson, J.D., Alexander, I.H., Grice, P. V., Evans, A.D., 2005. Does organic farming benefit biodiversity? Biol. Conserv. 122, 113–130. https://doi.org/10.1016/j.biocon.2004.07.018

https://www.bio-suisse.ch/ [WWW Document]. URL https://www.bio-

suisse.ch/en/home.php (accessed 5.25.19).
Isermeyer, H., 1952. Eine einfache Methode zur Bestimmung der Bodenatmung und der Karbonate im Boden. Zeitschrift für Pflanzenernährung, Düngung, Bodenkd. 56, 26–38. https://doi.org/10.1002/jpln.19520560107
Jäggi, W., 1976. Die Bestimmung der CO2-Bildung als Maβ der bodenbiologischen Aktivität. Schweiz landw Forsch. 15, 371–380.
Jansa, J., Erb, A., Oberholzer, H.R., Šmilauer, P., Egli, S., 2014. Soil and geography are more important determinants of indigenous arbuscular mycorrhizal communities than management practices in Swiss agricultural soils. Mol. Ecol. 23, 2118–2135. https://doi.org/10.1111/mec.12706
Jeanneret, P., Dennis, P., Franck, T., 2012. Spiders, in: Dennis, P., Bogers, M.M.B., Bunce, R.G.H., Herzog, F., Jeanneret, P. (Eds.), Biodiversity in Organic and Low-Input Farming Systems. Handbook for Recording Key Indicators. Alterra Report 2308, Wageningen, p. 92.
Jeanneret, P., Schüpbach, B., Luka, H., 2003. Quantifying the impact of landscape and habitat features on biodiversity in cultivated landscapes 98, 311–320. https://doi.org/10.1016/S0167-8809(03)00091-4
Jossi, W., Gunst, L., Zihlmann, U., Mäder, P., Dubois, D., 2009. DOK-Versuch: Eträge bei halber und praxisüblicher Düngung. AGRARForschung 16, 296–301.
Knapp, S., van der Heijden, M.G.A., 2018. A global meta-analysis of yield stability in organic and conservation agriculture. Nat. Commun. 9. https://doi.org/10.1038/s41467-018-05956-1
Larsen, E., Grossman, J., Edgell, J., Hoyt, G., Osmond, D., Hu, S., 2014. Soil biological properties, soil losses and corn yield in long-term organic and conventional farming systems. Soil Tillage Res. 139, 37–45. https://doi.org/10.1016/j.still.2014.02.002

Liu, X., Herbert, S.J., Hashemi, A.M., Zhang, X., Ding, G., 2006. Effects of agricultural management on soil organic matter and carbon transformation - a review. Plant, Soil Environ. 52, 531–543.

Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., Niggli, U., Series, N., May, N., 2002. Soil fertility and biodiversity in organic farming. Science 296, 1694–1697. https://doi.org/10.1126/science.1071148

Maestre, F.T., Quero, J.L., Gotelli, N.J., Escudero, A., Ochoa, V., Delgado-Baquerizo, M., García-Gómez, M., Bowker, M.A., Soliveres, S., Escolar, C., García-Palacios, P., Berdugo, M., Valencia, E., Gozalo, B., Gallardo, A., Aguilera, L., Arredondo, T., Blones, J., Boeken, B., Bran, D., Conceição, A.A., Cabrera, O., Chaieb, M., Derak, M., Eldridge, D.J., Espinosa, C.I., Florentino, A., Gaitán, J., Gatica, M.G., Ghiloufi, W., Gómez-González, S., Gutiérrez, J.R., Hernández, R.M., Huang, X., Huber-Sannwald, E., Jankju, M., Miriti, M., Monerris, J., Mau, R.L., Morici, E., Naseri, K., Ospina, A., Polo, V., Prina, A., Pucheta, E., Ramírez-Collantes, D.A., Ramão, R., Tighe, M., Torres-Díaz, C., Val, J., Veiga, J.P., Wang, D., Zaady, E., 2012. Plant species richness and ecosystem multifunctionality in global drylands. Science 335, 214–218.

Manning, P., Taylor, G., Hanley, M.E., 2015. Bioenergy, food production and biodiversity - an unlikely alliance? GCB Bioenergy 7, 570–576. https://doi.org/10.1111/gcbb.12173

Manning, P., van der Plas, F., Soliveres, S., Allan, E., Maestre, F.T., Mace, G., Whittingham, M.J., Fischer, M., 2018. Redefining ecosystem multifunctionality. Nat. Ecol. Evol. 2, 427–436. https://doi.org/10.1038/s41559-017-0461-7

Marc, P., Canard, A., 1997. Maintaining spider biodiversity in agroecosystems as a tool in pest control. Agric. Ecosyst. Environ. 62, 229–235. https://doi.org/10.1016/s0167-8809(96)01133-4

Martini, E.A., Buyer, J.S., Bryant, D.C., Hartz, T.K., Denison, R.F., 2004. Yield increases during the organic transition: improving soil quality or increasing experience? F. Crop. Res. 86, 255–266. https://doi.org/10.1016/j.fcr.2003.09.002

McGonigle, T.P., Miller, M.H., Evans, D.G., Fairchild, G.L., Swan, J.A., 1990. A new method which gives an objective measure of colonization of roots by vesicular-arbuscular mycorrhizal fungi. New Phytol. 115, 495–501. https://doi.org/10.1111/j.1469-8137.1990.tb00476.x

Michael, W., Waller, F., Zuccaro, A., Selosse, M.A., 2016. Sebacinales - one thousand and one interactions with land plants. New Phytol. 211, 20–40. https://doi.org/10.1111/nph.13977

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D.R., Chan, K.M.A., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H., Shaw, M.R., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Front. Ecol. Environ. 7, 4–11. https://doi.org/10.1890/080023

Oberholzer, H.-R., Fliessbach, A., Mäder, P., Mayer, J., 2009. Einfluss von biologischer und konventioneller Bewirtschaftung auf biologische Bodenqualitätsparameter : Entwicklungen im DOK Langzeitversuch nach pH-Regulierung, in: Werte - Wege - Wirkungen: Biolandbau Im Spannungsfeld Zwischen Ernährungssicherung, Markt Und Klimawandel. Beiträge Zur 10. Wissenschaftstagung Ökologischer Landbau. Band 1: Boden, Pflanzenbau, Agrartechnik, Umwelt- Und Naturschutz, Biolandbau Internation. 10. Wissenschaftstagung Ökologischer Landbau, Zürich, pp. 112–116.

Oehl, F., Jansa, J., Ineichen, K., Mäder, P., van der Heijden, M., 2011. Arbuskuläre Mykorrhizapilze als Bioindikatoren in Landwirtschaftsböden. Agrar. Schweiz 2, 304–311.

Oehl, F., Sieverding, E., Ineichen, K., Mäder, P., Boller, T., Wiemken, A., 2003. Impact of land use intensity on the species diversity of arbuscular mycorrhizal fungi in agroecosystems of Central Europe. Appl. Environ. Microbiol. 69, 2816–24. https://doi.org/10.1128/AEM.69.5.2816-2824.2003

Oliver, I., Beattie, A.J., 1996. Biology Invertebrate Morphospecies as Surrogates for Species : A Case Study. Conserv. Biol. 10, 99–109. https://doi.org/https://doi.org/10.1046/j.1523-1739.1996.10010099.x

Pimentel, D., 2005. Environmental and economic costs of the application of pesticides primarily in the United States. Environ. Dev. Sustain. 7, 229–252. https://doi.org/10.1007/s10668-005-7314-2

Pimentel, D., Hepperly, P., Hanson, J., Douds, D., Seidel, R., 2005. Environmental, energetic, and economic comparisons of organic and conventional farming systems. Bioscience 55, 573–582. https://doi.org/10.1641/0006-3568(2005)055[0573:EEAECO]2.0.CO;2

Ponisio, L.C., M'Gonigle, L.K.M., Mace, K.C., Palomino, J., de Valpine, P., Kremen, C., 2015. Diversification practices reduce organic to conventional yield gap. Proc R Soc B 282. https://doi.org/10.1098/rspb.2014.1396

Prechsl, U.E., Wittwer, R., van der Heijden, M.G.A., Lüscher, G., Jeanneret, P., Nemecek, T., 2017. Assessing the environmental impacts of cropping systems and cover crops: Life cycle assessment of FAST, a long-term arable farming field experiment. Agric. Syst. 157, 39–50. https://doi.org/10.1016/j.agsy.2017.06.011

R Core Team, 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Reeves, D.W., 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil Tillage Res. 43, 131–167.

https://doi.org/10.1016/s0167-1987(97)00038-x

Reganold, J.P., 1995. Soil quality and profitability of biodynamic and conventional farming systems: A review. Am. J. Altern. Agric. 10, 36–45. https://doi.org/https://doi.org/10.1017/S088918930000610X

Reganold, J.P., 1988. Comparison of soil properties as influenced by organic and conventional farming systems. Am. J. Altern. Agric. 3, 144–155. https://doi.org/10.1017/S0889189300002423

Reganold, J.P., Elliott, L.F., Unger, Y.L., 1987. Long-term effects of organic and conventional farming on soil erosion. Nature 330, 370–372. https://doi.org/10.1038/330370a0

Reganold, J.P., Wachter, J.M., 2016. Organic agriculture in the twenty-first century. Nat. plants 2. https://doi.org/10.1038/nplants.2015.221

Rigby, D., Cáceres, D., 2001. Organic farming and the sustainability of agricultural systems. Agric. Syst. 68, 21–40. https://doi.org/10.1016/S0308-521X(00)00060-3

Roberts, M.J., 1995. Spiders of Britain & Northern Europe. Harper Collins Publishers, London.

Samu, F., Szinetár, C., 2002. On the nature of agrobiont spiders, in: The Journal of Arachnology. Proceedings of the 15th International Congress of Arachnology. pp. 389–402. https://doi.org/https://doi.org/10.1636/0161-8202(2002)030[0389:otnoas]2.0.co;2

Schneider, M.K., Lüscher, G., Jeanneret, P., Arndorfer, M., Ammari, Y., Bailey, D., Balázs, K., Báldi, A., Choisis, J.P., Dennis, P., Eiter, S., Fjellstad, W., Fraser, M.D., Frank, T., Friedel, J.K., Garchi, S., Geijzendorffer, I.R., Gomiero, T., Gonzalez-Bornay, G., Hector, A., Jerkovich, G., Jongman, R.H.G., Kakudidi, E., Kainz, M., Kovács-Hostyánszki, A., Moreno, G., Nkwiine, C., Opio, J., Oschatz, M.L., Paoletti, M.G., Pointereau, P., Pulido, F.J., Sarthou, J.-P., Siebrecht, N., Sommaggio, D., Turnbull, L.A., Wolfrum, S., Herzog, F., 2014. Gains to species diversity in organically farmed fields are not propagated at the farm level. Nat. Commun. 5. https://doi.org/10.1038/ncomms5151

Schrama, M., de Haan, J.J., Kroonen, M., Verstegen, H., Van der Putten, W.H., 2018. Crop yield gap and stability in organic and conventional farming systems. Agric. Ecosyst. Environ. 256, 123–130. https://doi.org/10.1016/j.agee.2017.12.023

Seitz, S., Goebes, P., Puerta, V.L., Pereira, E.I.P., Wittwer, R., Six, J., van der Heijden, M.G.A., Scholten, T., 2019. Conservation tillage and organic farming reduce soil erosion. Agron. Sustain. Dev. 39. https://doi.org/10.1007/s13593-018-0545-z

Shepherd, M.A., Harrison, R., Webb, J., 2010. Managing soil organic matter - implications for soil structure on organic farms. Soil Use Manag. 18, 284–292. https://doi.org/10.1079/SUM2002134

Singh, J.S., Gupta, V.K., 2018. Soil microbial biomass: A key soil driver in management of ecosystem functioning. Sci. Total Environ. 634, 497–500. https://doi.org/10.1016/j.scitotenv.2018.03.373

Smith-Spangler, C., Brandeau, M.L., Hunter, G.E., Bavinger, J.C., Pearson, M., Eschbach, P.J., Sundaram, V., Liu, H., Schirmer, P., Stave, C., Olkin, I., Bravata, D.M., 2012. Are organic foods safer or healthier than conventional alternatives ? Ann. Intern. Med. 157, 348–366. https://doi.org/10.7326/0003-4819-157-5-201209040-00007

Soliveres, S., van Der Plas, F., Manning, P., Prati, D., Gossner, M.M., Renner, S.C., Alt, F., Arndt, H., Baumgartner, V., Binkenstein, J., Birkhofer, K., Blaser, S., Blüthgen, N., Boch, S., Böhm, S., Börschig, C., Buscot, F., Diekötter, T., Heinze, J., Hölzel, N., Jung, K., Klaus, V.H., Kleinebecker, T., Klemmer, S., Krauss, J., Lange, M., Morris, E.K., Müller, J., Oelmann, Y., Overmann, J., Pašalić, E., Rillig, M.C., Schaefer, H.M., Schloter, M., Schmitt, B., Schöning, I., Schrumpf, M., Sikorski, J., Socher, S.A., Solly, E.F., Sonnemann, I., Sorkau, E., Steckel, J., Steffan-Dewenter, I., Stempfhuber, B., Tschapka, M., Türke, M., Venter, P.C., Weiner, C.N., Weisser, W.W., Werner, M., Westphal, C., Wilcke, W., Wolters, V., Wubet, T., Wurst, S., Fischer, M., Allan, E., 2016. Biodiversity at multiple trophic levels is needed for ecosystem multifunctionality. Nature 536, 456–459. https://doi.org/10.1038/nature19092

Sunderland, K., Samu, F., 2000. Effects of agricultural diversification on the abundance, distribution, and pest control potential of spiders: a review. Entomol. Exp. Appl. 95, 1–13. https://doi.org/10.1046/j.1570-7458.2000.00635.x

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. Nature 418, 671–677. https://doi.org/10.1038/nature01014

Tu, C., Louws, F.J., Creamer, N.G., Paul Mueller, J., Brownie, C., Fager, K., Bell, M., Hu, S., 2006. Responses of soil microbial biomass and N availability to transition strategies from conventional to organic farming systems. Agric. Ecosyst. Environ. 113, 206–215. https://doi.org/10.1016/j.agee.2005.09.013

Tuck, S.L., Winqvist, C., Mota, F., Ahnström, J., Turnbull, L.A., Bengtsson, J., 2014. Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis. J. Appl. Ecol. 51, 746–755. https://doi.org/10.1111/1365-2664.12219

Tuomisto, H.L., Hodge, I.D., Riordan, P., Macdonald, D.W., 2012. Does organic farming reduce environmental impacts ? - A meta-analysis of European research. J. Environ. Manage. 112, 309–320. https://doi.org/10.1016/j.jenvman.2012.08.018

Vance, E.D., Brookes, P.C., Jenkinson, D.S., 1987. An extraction method for measuring soil microbial biomass C. Soil Biol. Biochem. 19, 703–707. https://doi.org/10.1016/0038-0717(87)90052-6

Verbruggen, E., Rillig, M.C., Wehner, J., Hegglin, D., Wittwer, R., van der Heijden, M.G.A., 2014. Sebacinales, but not total root associated fungal communities, are affected by land-use intensity. New Phytol. 203, 1036–1040. https://doi.org/10.1111/nph.12884

Verbruggen, E., Röling, W.F.M., Gamper, H.A., Kowalchuk, G.A., Verhoef, H.A., van der Heijden, M.G.A., 2010. Positive effects of organic farming on below-ground mutualists : large-scale comparison of mycorrhizal fungal communities in agricultural soils. New Phytol. 186, 968–979.

Verordnung über die Direktzahlungen an die Landwirtschaft [WWW Document], 2013. URL https://www.admin.ch/opc/de/classified-compilation/20130216/index.html (accessed 5.25.19).

Vierheilig, H., Coughlan, A.P., Wyss, U., Piché, Y., 1998. Ink and vinegar , a simple staining technique for arbuscular-mycorrhizal fungi. Appl. Environ. Microbiol. 64, 5004–5007.

Wagg, C., Bender, S.F., Widmer, F., van der Heijden, M.G.A., 2014. Soil biodiversity and soil community composition determine ecosystem multifunctionality. Proc. Natl. Acad. Sci. U. S. A. 111, 5266–5270. https://doi.org/10.1073/pnas.1320054111

Wardle, D.A., 1992. A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. Biol. Rev. 67, 321–358. https://doi.org/10.1111/j.1469-185X.1992.tb00728.x

White, T.J., Bruns, T., Lee, S., Taylor.J, 1990. Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics, in: Innis, M.A., Gefland, D.H., Sninsky, J.J., White, T.J. (Eds.), PCR Protocols: A Guide to Methods and Applications. Academic Press, Inc, San Diego, CA, USA, pp. 315–322.

Zihlmann, U., Jossi, W., Scherrer, C., Krebs, H., Oberholzer, H.-R., Vögeli, A., Nemecek, T., Richner, W., Brack, E., Gunst, L., Hiltbrunner, J., van der Heijden, M.G.A., Weisskopf, P., Dubois, D., Oehl, F., 2010. Integrierter und biologischer Anbau im Vergleich. Resultate aus dem Anbausystemversuch Burgrain 1991 bis 2008, ART-Bericht 722.

Figure captions

Fig. 1. Map of Switzerland with the 34 study sites in the Cantons of Aargau, Zurich and Thurgau. One crop field was selected at each study site and was assigned to one of the four management groups: 1) conventionally managed farms (CONV); 2) fields in transition to organic farming (in the 1st–3rd year; TRAN); 3) fields converted moderately long ago (9–13 years; BIO(9), 4) or fields that had been subjected to long-term organic farming (15–32 years, BIO(15). [Source: Swisstopo (2018)]

Fig. 2. Comparison of four different multifunctionality scenarios representing different land-use perspectives: (M1) “production” with 50% of the weight for “productivity” and 50% weight for the remaining variables; (M2) “sustainable soils” with 25% of the weight for each “productivity “, “soil microbial activity” and “soil fertility” and 25% weight for the remaining variables; (M3) “equal weight multifunctionality” weighs all EF categories equally; and (M4) “biodiversity” with 50% of the weight on the EF category “biodiversity”.

Fig. 3. Linear regression plots showing the relationships between the duration of organic management and maize yield (A), wheat yield (B), weed cover in maize (C) and weed cover in wheat (D). Fields were assigned to four management groups: 1) conventionally managed farms (CONV); 2) fields in transition to organic farming (in the 1st–3rd year; TRAN); 3) fields converted moderately long ago (9–13 years; BIO(9), 4) or fields that had been subjected to long-term organic farming (15–32 years, BIO(15). The duration of organic management is expressed as the number of years since the conversion from conventional to organic management. The black line indicates the linear regression line and the gray region the 95% confidence interval. Conventional farms were plotted for the comparison but are not included in the regression analysis.

Fig. 4. Principal component analysis (PCA) comparing maize (A) and wheat (B) fields under conventional management (CONV); fields in transition to organic management (in the 1st–3rd year; TRAN), fields managed organically between nine and 13 years (BIO(9)) or fields that had been subjected to long-term organic farming (15–32 years, BIO(15). The same variables (eight for maize and 13 for wheat) were used to calculate ecosystem multifunctionality. Variables were standardized prior to the application of PCA. The principal component axes 1 and 2 (PC1 and PC2 together explained 57.3% of the total variation in the response of the maize fields and 53,2% of the wheat fields, respectively. The four ellipses represent 68% confidence around each management group. Variable abbreviations are: weed %= weed cover, P= soil P, K=soil K, Mg=soil Mg, AMF %=AMF colonization, resp=respiration, weed S= weed species richness, weed J= weed species evenness, spid S=spider species richness, spid J=spider species evenness, fungi S=OTU richness of root associated fungi, fungi J=OTU richness of root associated fungi, spid abund=spider abundance.

Fig. 5. Multifunctionality in response to the different management and the four different scenarios: (A) M1) “production” with 50% of the weight for “productivity” and 50% weight for the remaining categories; (B) M2) “sustainable soils” with 25% of the weight for each “productivity “, “soil microbial activity” and “soil fertility” and 25% for the remaining categories; (C) M3) “equal weight multifunctionality” where all EF categories are weighted equally; and D) M4) “biodiversity” with 50% of the weight on the EF category “biodiversity” and 50% for the remaining categories (Fig. 2). Each field

was assigned to one of the four management groups: 1) conventionally managed farms (CONV); 2) fields in transition to organic farming (in the 1st–3rd year; TRAN); 3) fields converted moderately long ago (9–13 years; BIO(9), 4) or fields that had been subjected to long-term organic farming (15–32 years, BIO(15). Bold lines represent medians, black crosses the means, boxes the first and third quantiles. Ns indicates non-significant differences among treatments at an alpha value of 0.05.

Table 1. Mean, standard errors (SE), sample size (N) and the statistical output of the Kruskal-Wallis test for the assessed variables in maize (N=34). P-values in bold indicate significant effects at $P = 0.05$. The farms were divided into four groups: 1) conventionally managed farms (CONV; 9 farms); 2) organic farms that had recently been converted (TRAN; 9 farms; 1–3 years); 3) moderately long ago (BIO(9); 7 farms; 9–13 years), 4) or had been subjected to long-term organic farming (BIO(15); 9 farms; 15–32 years). Variables included in the multifunctionality assessment are indicated as indicator variables. Different letters after the mean indicate significant differences among management groups, at an alpha rejection value set to 0.05.

Variable	**Indicator**	**CONV**			**TRAN**			**BIO(9)**			**BIO(15)**				
	variable	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**H(df=3)**	**p-value**
Yield (dt DM/ha)	yes	207.089	5.403	9	196.478	9.816	9	190.229	6.291	7	196.550	12.089	8	2.590	0.459
Weed cover (%)	yes	2.033 **a**	0.661	9	27.711 **b**	5.714	9	33.229 **b**	10.046	7	38.222 **b**	9.257	9	17.832	**< 0.001**
Weed species richness *(S)*	yes	1.889 **a**	0.484	9	5.667 **b**	0.833	9	7.286 **b**	1.107	7	8.889 **b**	1.047	9	18.982	**< 0.001**
Weed species evenness (*J*)	yes	0.518	0.150	7	0.750	0.038	8	0.707	0.034	7	0.702	0.045	9	1.298	0.730
Weed diversity (*H*)	no	0.428 **a**	0.151	9	1.196 **b**	0.177	9	1.365 **b**	0.171	7	1.491 **b**	0.130	9	15.309	**0.002**
Spider species richness *(S)*	yes	6.111	0.992	9	6.875	0.833	8	5.830	1.352	6	6.500	0.627	8	0.662	0.882
Spider species evenness *(J)*	yes	0.828	0.036	8	0.745	0.052	8	0.710	0.079	6	0.776	0.042	8	1.688	0.640
Spider diversity (*H*)	no	1.373	0.212	9	1.360	0.099	8	1.090	0.156	6	1.415	0.102	8	2.888	0.409
Spider diversity (Chao1)	no	18.850	2.858	8	17.014	3.233	8	20.290	6.763	5	19.774	3.934	8	0.485	0.922
Spider abundance	yes	6.889	1.399	9	11.000	1.783	8	11.000	4.435	6	7.375	2.112	8	3.639	0.303
AMF colonization (%)	yes	43.333	4.503	9	35.556	3.379	9	43.143	6.759	7	46.889	3.549	9	3.824	0.281
Fertilizer-N (kg $N_{soluble}$/ha)	no	152.000 **a**	16.562	9	115.111 **ab**	20.259	9	90.800 **ab**	7.851	5	84.875 **b**	14.593	8	8.255	**0.041**
Fertilizer-P (kg P_2O_5/ha)	no	102.222	18.125	9	124.222	15.259	9	107.400	31.384	5	102.625	14.931	8	1.792	0.617
Fertilizer-K (kg K_2O/ha)	no	226.444	38.639	9	286.222	37.034	9	289.400	15.224	5	216.142	25.078	7	4.719	0.194

Table 2. Mean, standard error (SE) and sample size (N) and the statistical output of the Kruskal-Wallis test for the assessed variables in wheat fields (N=24). P-values in bold indicate significant effects at *P* = 0.05. The farms were divided into four groups: 1) conventionally managed farms (CONV; 7 farms); 2) organic farms that had recently been converted (TRAN; 6 farms; 1–3 years); 3) moderately long ago (BIO(9); 5 farms; 9–13 years), 4) or had been subjected to long-term organic farming (BIO(15); 6 farms; 15–32 years). Variables included in the multifunctionality assessment are indicated as indicator variables. Different letters after the mean indicate significant differences among management groups, at an alpha rejection value set to 0.05.

Variable	Indicator	CONV			TRAN			BIO(9)			BIO(15)				
	variable	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	H(df=3)	p-value
Yield (dt DM/ha)	yes	64.371	4.093	7	50.317	3.473	6	50.460	3.6140	5	49.517	3.500	6	6.962	0.073
Weed cover (%)	yes	1.233 **a**	0.596	7	11.767 **b**	2.367	6	15.420 **b**	11.176	5	13.450 **b**	3.557	6	12.301	**0.006**
Weed species richness *(S)*	yes	3.143 **a**	0.595	7	11.000 **b**	1.238	6	8.400 **ab**	1.720	5	9.667 **b**	1.229	6	14.468	**0.002**
Weed species evenness (*J*)	yes	0.680	0.100	6	0.527	0.083	6	0.687	0.096	5	0.491	0.055	6	2.054	0.561
Weed diversity (*H*)	no	0.668	0.174	7	1.262	0.210	6	1.263	0.267	5	1.116	0.107	6	5.218	0.157
OTU richness *(S)* of root associated fungi	yes	57.430	6.679	7	57.167	3.554	6	58.600	4.250	5	54.000	5.994	6	0.660	0.883
OTU evenness *(J)* of root associated fungi	yes	0.607	0.043	7	0.531	0.053	6	0.586	0.065	5	0.471	0.072	6	3.059	0.383
OTU diversity (*H*) of root associated fungi	no	2.453	0.220	7	2.146	0.225	6	2.397	0.303	5	1.903	0.331	6	2.223	0.527
Microbial biomass C (mg C/kg soil)	yes	551.587	104.256	7	612.900	78.740	6	646.340	104.600	5	774.567	99.445	6	2.369	0.500
Respiration (mg CO2-C/kg soil*h)	yes	0.569	0.085	7	0.6708	0.071	6	0.669	0.094	5	0.797	0.101	6	3.115	0.374
AMF colonization (%)	yes	27.857 **a**	5.705	7	47.833 **ab**	2.088	6	54.000 **b**	2.074	5	42.000 **a**	3.183	6	13.905	**0.003**
C_{org} (%)	yes	1.817	0.210	7	1.943	0.186	6	2.134	0.132	5	2.218	0.154	6	3.937	0.268
Soil K (mg/100g soil)	yes	2.657 **ab**	0.324	7	1.283 **b**	0.221	6	1.640 **b**	0.434	5	4.867 **a**	1.147	6	14.192	**0.003**
Soil P (mg/100g soil)	yes	11.043	1.149	7	6.200	2.019	6	8.9200	1.605	5	13.483	2.794	6	6.569	0.087
Soil Mg (mg/100g soil)	yes	13.943	3.587	7	15.783	2.362	6	21.100	7.417	5	19.867	5.197	6	2.048	0.563
Soil pH March	no	6.857	0.208	7	6.767	0.329	6	6.660	0.304	5	7.200	0.200	6	2.196	0.533
Soil pH July	no	6.700	0.129	7	6.567	0.171	6	6.500	0.084	5	6.817	0.091	6	4.197	0.241

Fertilizer-N (kg $N_{soluble}$/ha)	no	117.667 **a**	9.333	6	86.500 **ab**	16.506	6	61.600 **b**	5.418	5	60.400 **b**	12.995	5	8.792	**0.032**
Fertilizer-P (kg P_2O_5/ha)	no	26.833	14.554	6	75.333	14.033	6	61.200	9.404	5	66.800	7.493	5	6.618	0.085
Fertilizer-K (kg K_2O/ha)	no	57.667 **a**	27.559	6	157.333 **ab**	22.317	6	187.200 **b**	21.386	5	210.200 **b**	24.132	5	11.396	**0.010**

Table 3. For the multifunctionality assessment, individual parameters (indicator variables) were assigned to five ecosystem function (EF) categories, namely: “productivity”, “soil fertility”, “soil microbial activity”, “biodiversity conservation”, and “potential biocontrol of pests”. For each indicator variable it is indicated whether it was assessed for one or both crops (M= maize, W=wheat). *Weed cover was defined as a disfunction because it is an undesirable aspect for farmers.

Ecosystem function (EF) category	**Indicator variable**	**Crop**
Productivity	Yield	M, W
	Weed cover *	M, W
Soil fertility	C_{org}	W
	Soil P	W
	Soil K	W
	Soil Mg	W
Soil microbial activity	AMF colonization	M, W
	Microbial biomass C	W
	Soil Respiration	W
Biodiversity conservation	Weed species richness (*S*)	M, W
	Weed species evenness (*J*)	M, W
	Spider species richness (*S*)	M
	Spider species evenness (*J*)	M
	OTU richness of root associated fungi (*S*)	W
	OTU evenness of root associated fungi (*J*)	W
Potential biocontrol of pests	Spider abundance	M

962 **Fig. 1.**

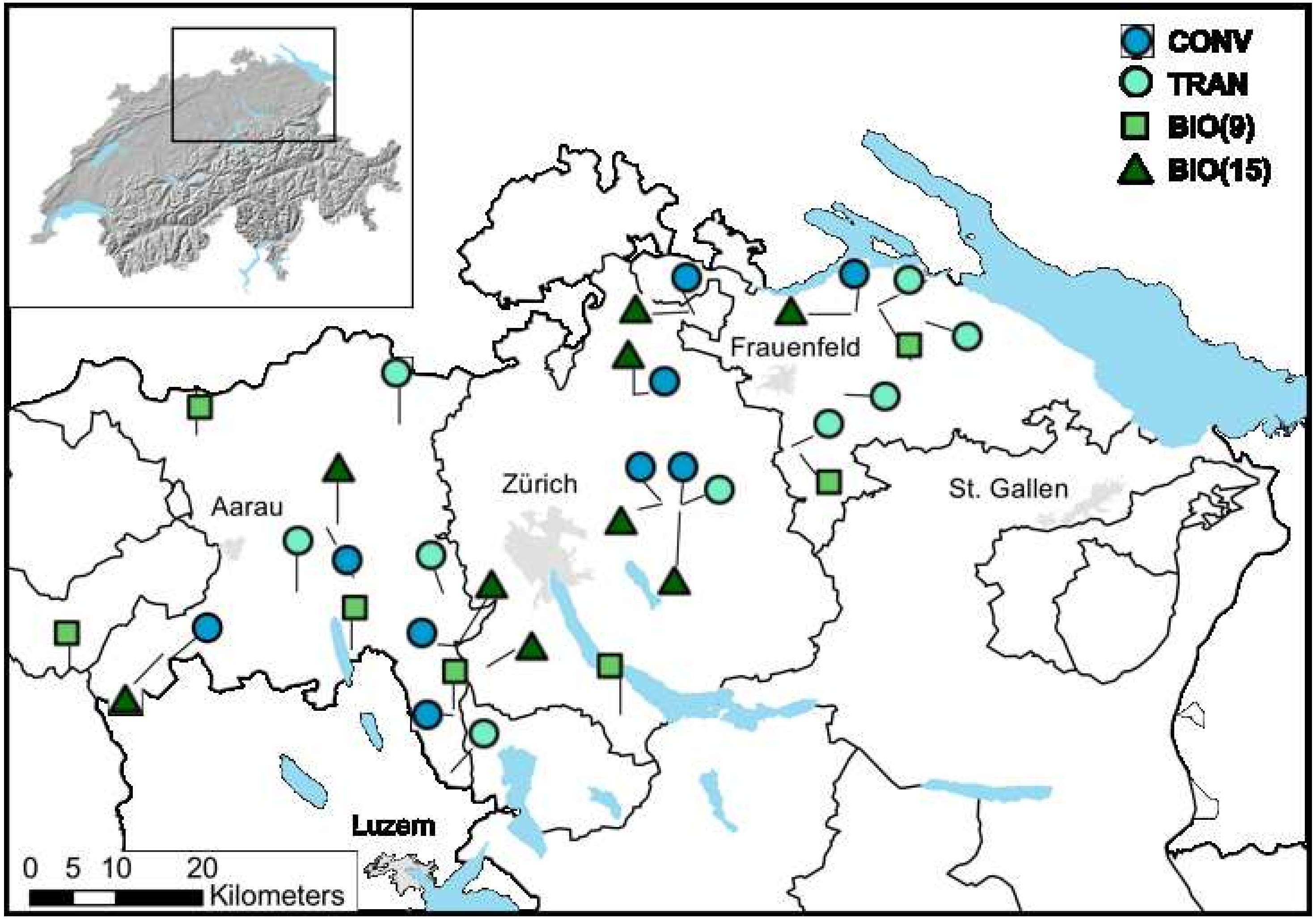
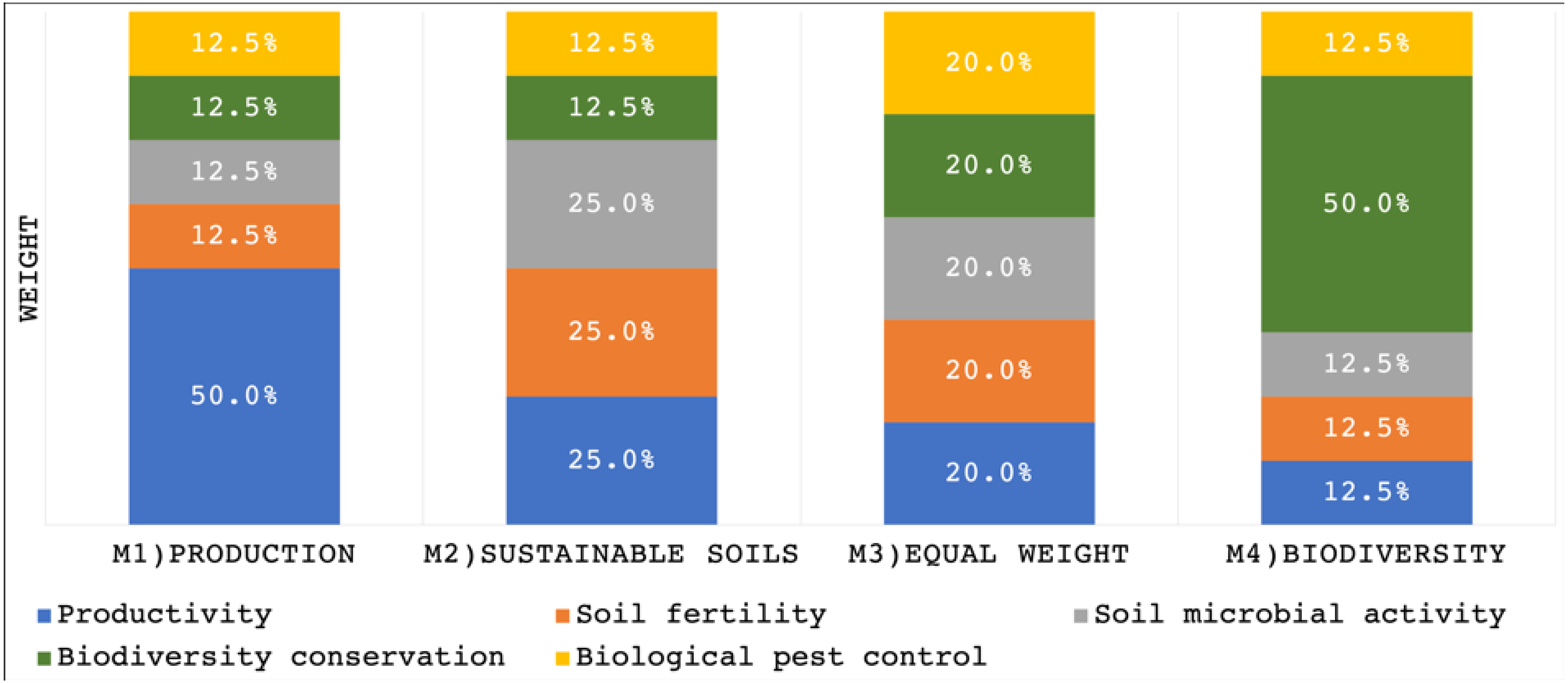
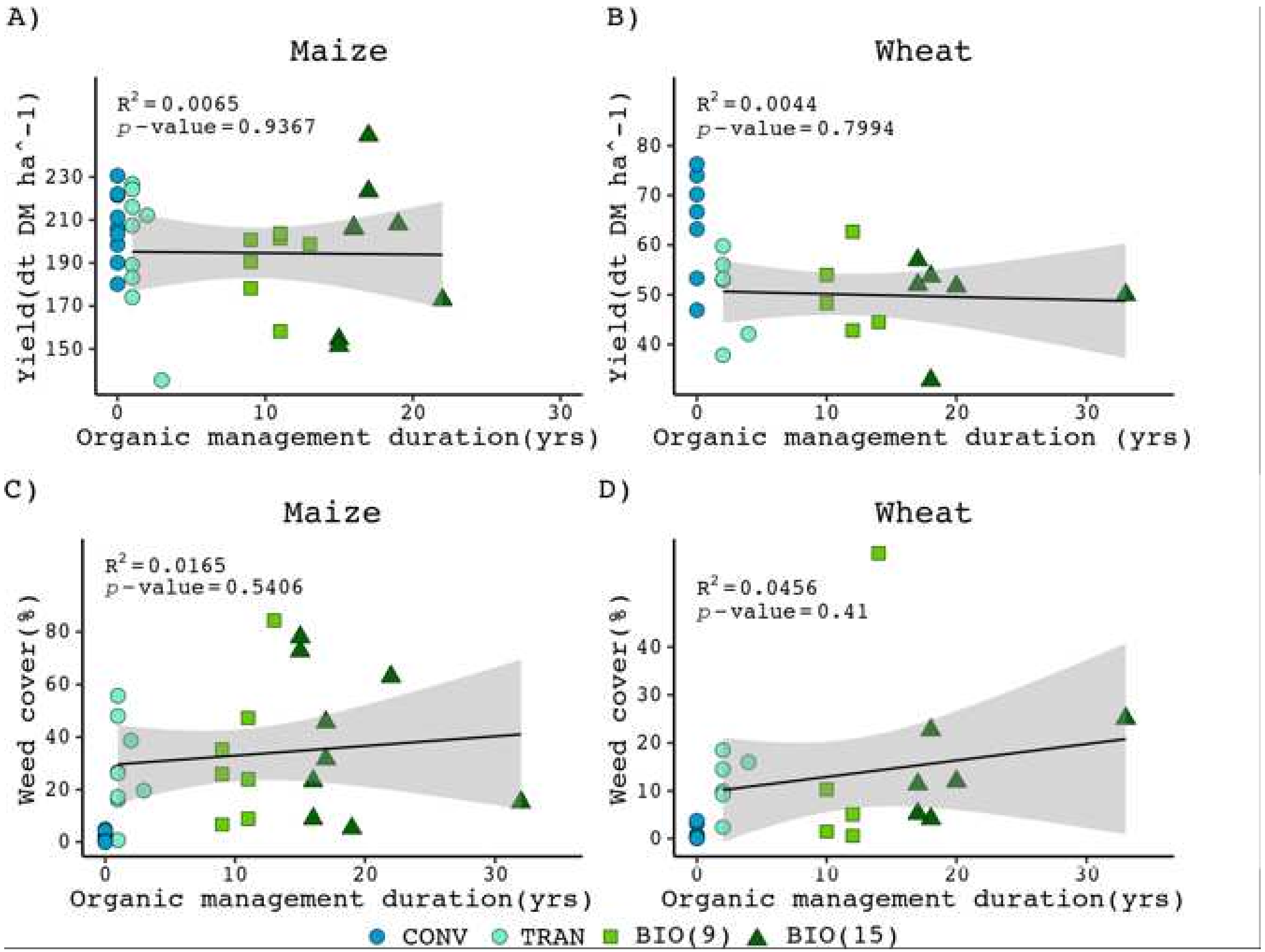
963 
CONV
TRAN
BIO(9)
BIO(15)
Frauenfeld
Zürich
Aarau
St. Gallen
Luzern
0 5 10 20
Kilometers

Fig. 2.


WEIGHT
12.5%
12.5%
12.5%
12.5%
50.0%
12.5%
12.5%
25.0%
25.0%
25.0%
20.0%
20.0%
20.0%
20.0%
20.0%
12.5%
50.0%
12.5%
12.5%
12.5%
M1)PRODUCTION
M2)SUSTAINABLE SOILS
M3)EQUAL WEIGHT
M4)BIODIVERSITY
Productivity
Soil fertility
Soil microbial activity
Biodiversity conservation
Biological pest control

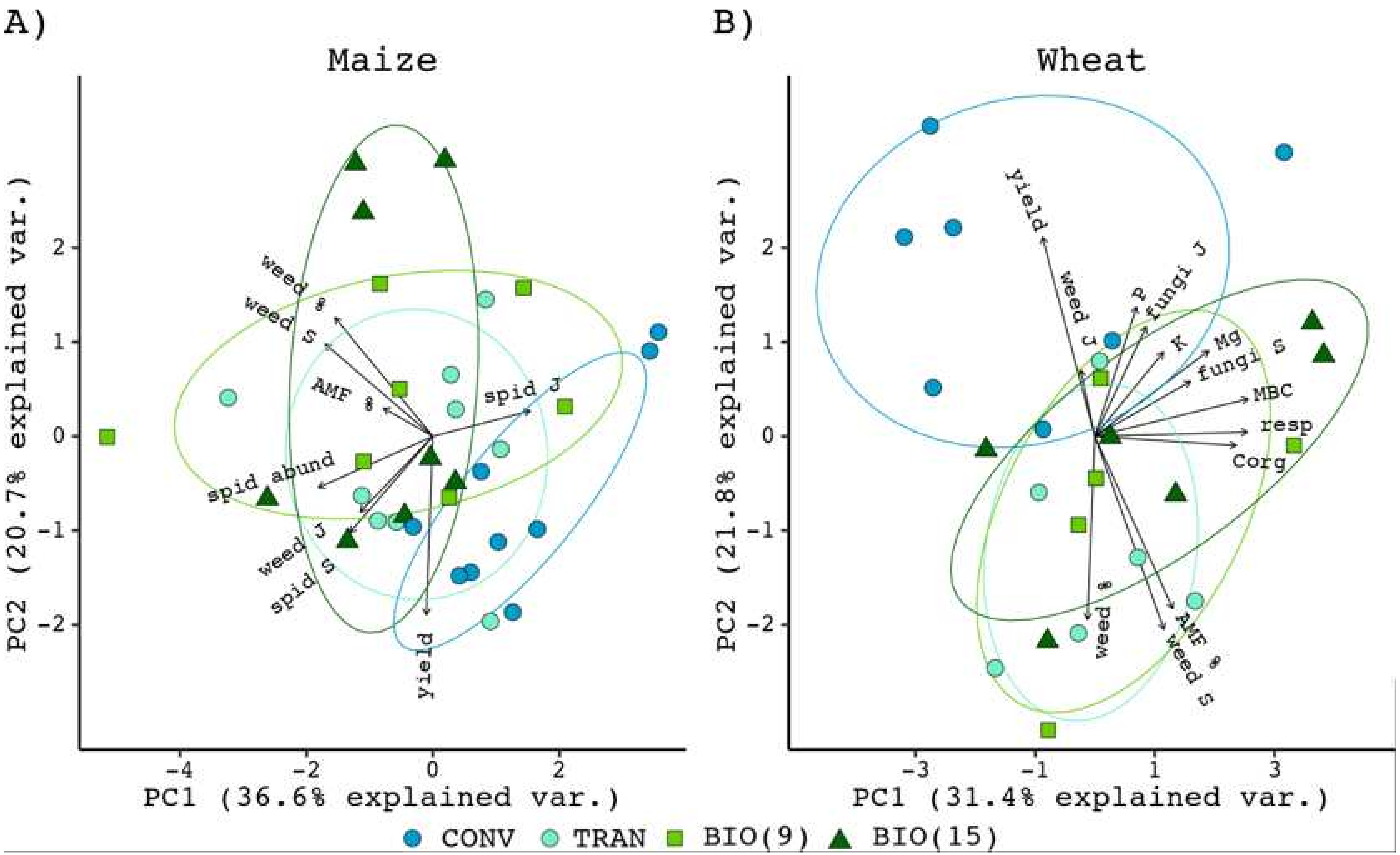
967 **Fig. 3.**



A)
Maize
R^2 = 0.0065
p-value = 0.9367
Yield(dt DM ha^-1)
230
210
190
170
150
0
10
20
30
Organic management duration(yrs)
B)
Wheat
R^2 = 0.0044
p-value = 0.7994
Yield(dt DM ha^-1)
80
70
60
50
40
0
10
20
30
Organic management duration (yrs)
C)
Maize
R^2 = 0.0165
p-value = 0.5406
Weed cover(%)
80
60
40
20
0
0
10
20
30
Organic management duration(yrs)
D)
Wheat
R^2 = 0.0456
p-value = 0.41
Weed cover(%)
40
30
20
10
0
0
10
20
30
Organic management duration(yrs)
CONV
TRAN
BIO(9)
BIO(15)

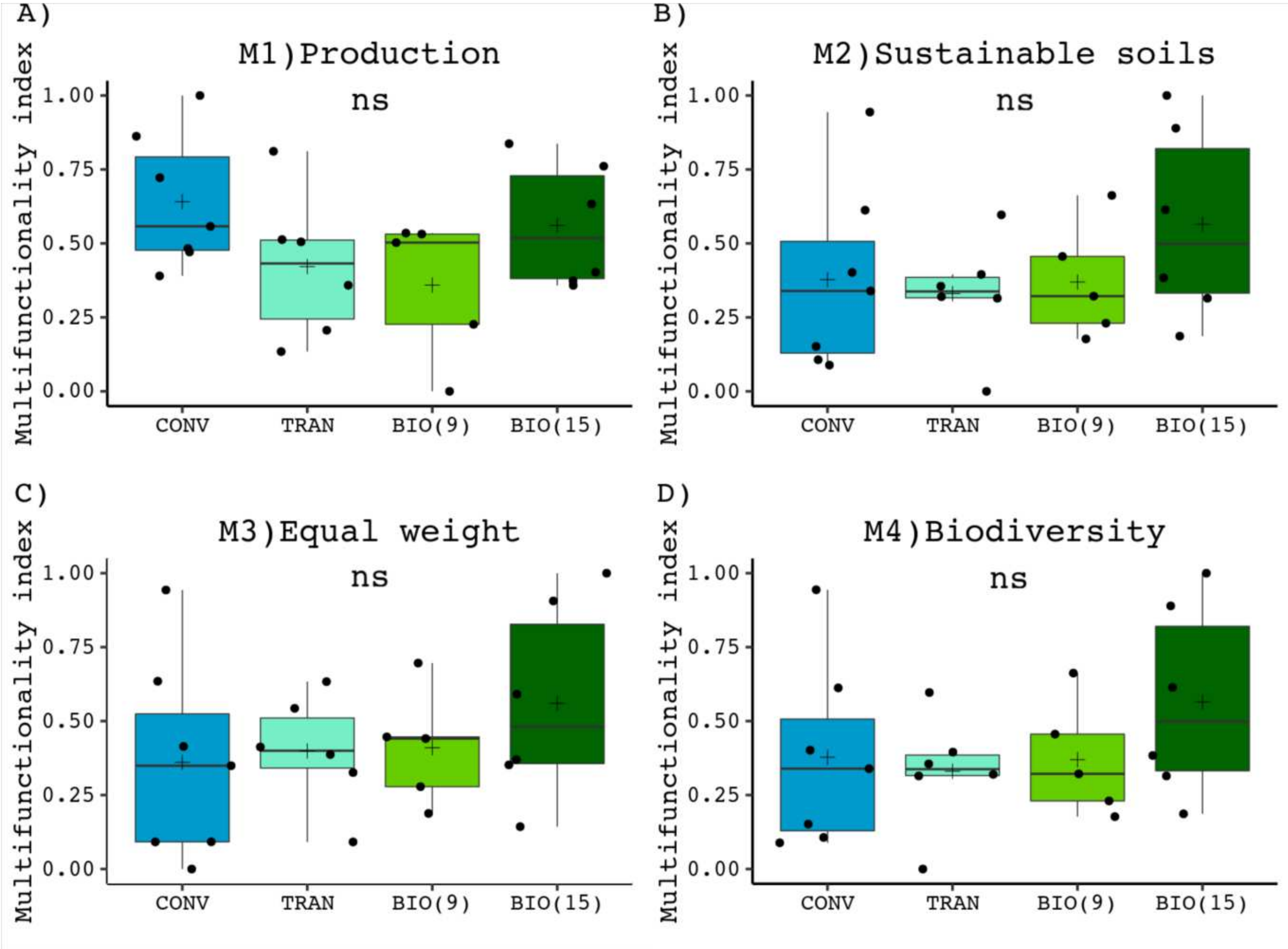
968

Fig. 4.



A)
Maize
B)
Wheat
PC2 (20.7% explained var.)
PC1 (36.6% explained var.)
PC2 (21.8% explained var.)
PC1 (31.4% explained var.)
weed %
weed S
AMF %
spid J
spid abund
weed J
spid S
yield
fungi J
P
K
Mg
fungi S
MBC
resp
Corg
weed %
AMF %
weed S
CONV
TRAN
BIO(9)
BIO(15)

971 **Fig.5.**


A)
M1)Production
ns
B)
M2)Sustainable soils
ns
C)
M3)Equal weight
ns
D)
M4)Biodiversity
ns
Multifunctionality index
1.00
0.75
0.50
0.25
0.00
CONV
TRAN
BIO(9)
BIO(15)

972